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OCLE: A European open access database on climate change effects on littoral and oceanic ecosystems

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1. Introduction

Studies on historical and future distribution of marine species are frequently limited by the lack of relevant data on abiotic components (IPCC, 2014), especially when working over large areas (Robinson et al., 2017). Important advances have been achieved in the last years regarding availability of global information on physical and chemical driven forces affecting species distributions. WorldClim (Hijmans et al., 2005) marked a milestone in terrestrial species distribution studies, as it opened the opportunity to address global research studies with high resolution. Other databases including historical and projected variables in the terrestrial environment, mainly temperature and precipitation, such as Climond (Kriticos et al., 2012), Climate wizard (Girvetz et al., 2009) or Chelsea (Karger et al., 2016) have emerged recently. However, in the marine environment the number of global databases is limited. Bio-Oracle is the most valuable reference because it provides surface and benthic layers for water temperature, salinity, nutrients, chlorophyll, sea ice, current velocity, phytoplankton, primary productivity, iron and light at high resolution and global coverage (Assis et al., 2017; Tyberghein et al., 2012). Other remarkable databases are MARSPEC (Sbrocco and Barber, 2013), offering variables derived from bathymetry, slope, salinity and sea surface temperature, Aquamaps (Ready et al., 2010), focused on marine animals, or Hexacoral (Fautin and Buddemeier, 2002), with the aim to understand spatial and temporal patterns in biogeochemistry and biogeography. Some databases cover both land and sea areas, such as the MERRAclim (Vega et al., 2017), which offers decadal data of 19 derived variables of air temperature and humidity atmospheric water vapour.

Despite the important contributions of these marine databases, different important questions still require further developments. The first issue to be considered is the common absence of data on hydrodynamic variables (e.g. wave height, current speed or bottom and wind stress) with global coverage, although there is considerable evidence of their relevance in species distribution (Callaghan et al., 2015; de la Hoz et al., 2018; Ramos et al., 2014). Among these, the bottom shear stress is very important when studying benthic vegetation because its influence on their settlement and survival (Pace et al., 2017), but this kind of information does not seem to be currently available for large areas. A second concern refers to the lack of homogeneity in the time intervals used to calculate different parameters and consequent limitations for long-term multi-criteria retrospective analysis. The third issue that rises in this analysis applies to the ecological reliability of the selected parameters. Most databases only provide mean, minimum and maximum values for long periods, although many environmental triggers influencing life cycles and species distributions seem to act on extreme events occurring at shorter time scales (Galván et al., 2016; Seabra et al., 2015), especially in a climate change context (Lima and Wethey, 2012). Therefore, the formulation of biologically-meaningful parameters using datasets and increasing time resolutions arises as two key steps in order to get more realistic results. Moreover, when defining parameters for projected futures, it is essential to work with the best information available, as the General Circulation Models (GCMs), that take into account the Representative Concentration Pathways (RCPs) introduced in the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014).

Accordingly, the improvement of the available databases must address those gaps in order to adapt them to current and future needs for species distribution studies. Homogeneous and complete high resolution data, integrated at different time scales, ecological-sounded parameters, based on abiotic conditions that determine the ecology of the species of interest have to be included. Additionally, raw data have to be controlled and homogenised to guarantee the quality of the derived products. Concerning temporal periods, different resolutions should be available to allow researchers to define specific parameters for each species. Besides, data should fit to the spatial scale of the work, covering the study area with the necessary detail. Finally, the access to the data have to be free and very intuitive for users, reducing to the maximum the weight and the computing resources used for getting the information.

Trying to comply with these requirements and using the best data available, to our best knowledge, this study presents the open access database on climate change effects on littoral and oceanic ecosystems (OCLE), an ecological-driven database of present and future hazards for marine life in Europe. As a first step the database is oriented toward

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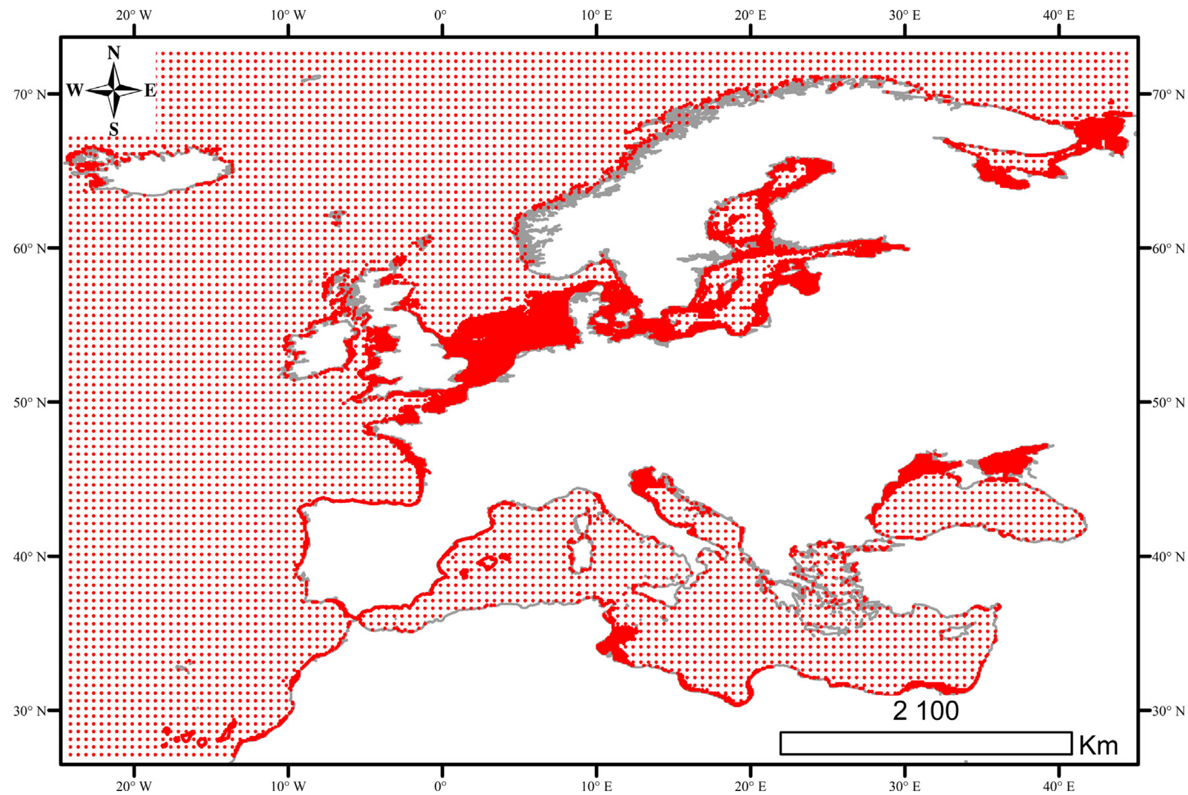

Fig. 1. Representation of the "virtual sensors" integrated in the OCLE database.

seagrasses and algae, due to their key role in the food chain of marine ecosystems, contributing to the maintenance of biodiversity and providing ecosystem services (Duarte et al., 2013; Mazarrasa et al., 2017; Ondiviela et al., 2014). However, the aim of OCLE is to provide researchers with open access accurate information for marine studies, not only for coastal studies, but also in oceanic waters.

2. Material and methods

2.1. Study area

All the regional European seas have been included in OCLE, at two different resolutions: 0.1° for coastal waters (until 50 m depth), to better characterize the potential habitat of coastal ecosystems; and, 0.5° for oceanic waters. That way, the OCLE database can provide information for a total of 18,200 points considered as "virtual sensors", of which 12,074 correspond to coastal areas and 6126 to offshore areas (Fig. 1).

2.2. Variables and parameters

The variables included in OCLE were first selected because of their functional relationship with seagrasses and macroalgae distributions. Those variables with a heterogeneous distribution in space and/or time were discarded. General meteo-oceanographic variables (hereinafter referred to as met-ocean variables) were considered first, including different physical and chemical factors, such as temperature (Fralick et al., 1990; Valle et al., 2014), light (Best et al., 2001; Larkum et al., 2006), salinity (Nejrup and Pedersen, 2008; Touchette, 2007) or nutrients (Hughes et al., 2004; Martínez et al., 2012b). Those were complemented with other variables related to the stressful conditions that limit intertidal organisms distributions, such as desiccation, a decisive survival factor characterized by the tidal range (Pearson et al., 2009), the wind speed (Lipkin et al., 1993), the significant wave height (Jones et al., 2015) and sea level (Short and Neckles, 1999), especially under future scenarios. A final group of variables regarding exposure of subtidal species to uprooting conditions was also taken into account. Stress to high energy conditions is characterized by the bottom orbital speed (Young et al., 2015), the currents speed (Infantes et al., 2011) and the, significantly more complex variable, bottom shear stress (Pace et al., 2017).

For each variable, a complete set of parameters was selected in order to reflect in a more holistic perspective the state of the environment, as a proxy of ecological processes. For historical data, the maximum, minimum, mean, standard deviation, range and percentiles 10, 25, 50, 75 and 90 were calculated at each virtual sensor, for seasonal, monthly, yearly, five-yearly and full (1985–2015) periods (Fig. 2). Besides, according to the more detailed information available and their close relationship to macrophytes distributions, some specific and relevant parameters to detect changes in extreme conditions of sea and air temperatures (i.e. number of consecutive days over the percentile 90 (Torresan et al., 2016)), and for the shear stress (i.e. number of days over 2.2 Nt/m^2 (Vousdoukas et al., 2012)) were calculated (Fig. 2). Furthermore, for future projections, the same group of parameters were calculated on a seasonal, yearly and full period, considering both the near-term (2040–2069) and the long term (2070–2099) for two RCPs, namely RCP 4.5 and RCP 8.5.

2.3. Data sources and methods

Historical data were compiled from satellite (Schuckmann et al., 2016), reanalysis (Cid et al., 2014; Donlon et al., 2012; Perez et al., 2017; Reguero et al., 2012; Saha et al., 2010; Stark et al., 2007) or *in situ* measurements (Weatherall et al., 2015).

A quality control was established along all steps. First, only validated sources were selected, either with instrumental data (Garnesson et al., 2016; Perruche et al., 2015; Saha et al., 2014, 2010; Schuckmann et al., 2016), remotely sensed information (Donlon et al., 2012) or both of them (Cid et al., 2014; Perez et al., 2017). To get a temporal and spatially homogeneous database, only sources with time series longer

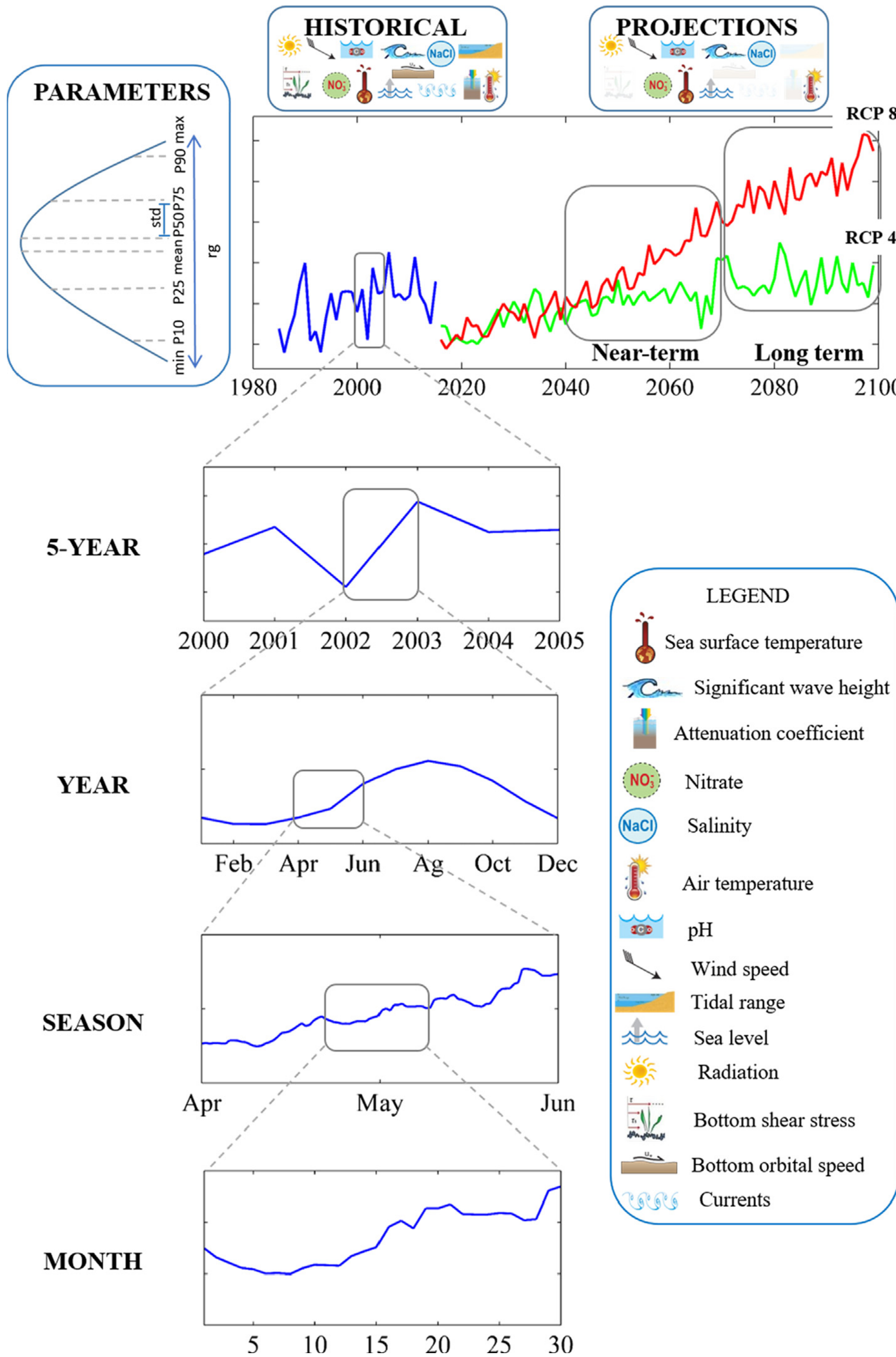

Fig. 2. Parameters calculated and their temporal resolution. max, maximum; min, minimum; P, percentile; std, standard deviation; rg, range.

than 15 years and a spatial resolution lower than 0.5° were taken into account. Final selected data were compared with existing studies (e.g. Rhein et al., 2013; Collins et al., 2013; EEA, 2009).

For future projections data from the fifth phase of the Coupled Model Intercomparison Project (CMIP5, Taylor et al., 2012) were used. CMIP5 provides results of a set of coordinated climatic model experiments using GCMs at two times scales, a near-term (2040–2069) and a long-term period (2070–2099) for different RCPs. This experimental set has been selected for its high skill to represent projections at the North-East Atlantic Region (Perez et al., 2014) and because it is the reference set provided by the IPCC for climate research and impact and risk assessment. Quality assurance and control procedures for projected data were based on mean squared errors (MSE) between the historical data series selected and those of the GCMs for the reference period (1985–2005). This analysis was carried out for each of the Marine Strategy Framework Directive region (European Commission, 2008) to avoid a bias by local processes. Outliers (GCMs with more than 20% of their values out of the limits within the $MSE_{mean} \pm MSE_{std}$) were discarded (Chai and Draxler, 2014). More detailed information is available in Supplementary data 1.

The final data sources are shown in Table 1. Historical and projected periods are shown for each variable and final GCMs selected are named. More detailed information about original data sources and GCMs is available in Supplementary data 2.

For each variable, data available from the original sources closest to the defined virtual sensors were selected. Bottom shear stress

Table 1
Variables selected with indication of periods, sources and the applied method to data gathering. For projections, the GCMs used are specified.

Variable	Period	Method	Source
Sea surface temperature (SST) (°C)	01/01/1985 – 31/12/2015	Reanalysis	OSTIA dataset (NASA)
	01/01/2010 – 31/12/2099	Projections CNRM-CM5, GFDL-ESM2G, IPSL-CM5A-LR, IPSL-CM5A-MR, MPI-ESM-LR, MPI-ESM-MR	CMIP5
Significant wave height (Hs) (m)	01/01/1985 – 31/12/2015	Reanalysis	GOW (IH Cantabria)
	01/01/2010 – 31/12/2099	Projections GFDL-ESM2G, GFDL-ESM2M, IPSL-CM5A-LR, MPI-ESM-LR, MPI-ESM-MR	CMIP5
Bathymetry (m)	–	Satellite and *in situ* measurements	GEBCO 2014 (BODC)
Light attenuation coefficient (Kd) (m^{-1})	25/01/1998–27/12/2015	Satellite measurements	Copernicus Marine System (ESA)
Substrate	–	Renalysis and *in situ* measurements	EMODNET EUSeaMap
Nitrate (mol/m^3)	16/01/1998–16/12/2014	Reanalysis	Copernicus Marine System (ESA)
	15/01/2010–15/12/2099	Projections IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR, MPI-ESM-LR, MPI-ESM-MR	CMIP5
Salinity(psu)	01/01/1985 – 31/12/2015	Reanalysis	CFSR
	15/01/2010–15/12/2099	Projections IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR	CMIP5
Air temperature (°C)	01/01/1985 – 31/12/2015	Reanalysis	CFSR
	01/01/2010 – 31/12/2099	Projections CNRM-CM5, GFDL-ESM2G, GFDL-ESM2M, IPSL-CM5A-LR, IPSL-CM5A-MR, MPI-ESM-LR, MPI-ESM-MR	CMIP5
pH	13/01/1985 – 08/11/2005	Reanalysis	CMIP5
	16/01/2010–16/12/2099	Projections IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR, MPI-ESM-LR	CMIP5
Wind speed (m/s)	01/01/1985 – 31/12/2015	Reanalysis	CFSR
	01/01/2010 – 31/12/2099	Projections CNRM-CM5, GFDL-ESM2G, GFDL-ESM2M, IPSL-CM5A-LR, IPSL-CM5A-MR, MPI-ESM-MR	CMIP5
Tidal range (m)	01/01/1985 – 31/12/2013	Reanalysis	GOST (IH Cantabria)
Sea level rise (m)	–	–	–
	01/01/2010 – 31/12/2099	Projections (IPCC, 2014)	(Slangen et al., 2014)
Radiation (W/m^2)	01/01/1985 – 31/12/2005	Projections GFDL-ESM2G, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR, MPI-ESM-LR, MPI-ESM-MR	CMIP5
	01/01/2010 – 31/12/2099	Projections GFDL-ESM2G, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR, MPI-ESM-LR, MPI-ESM-MR	CMIP5
Bottom shear stress (N/m^2)	01/01/1985 – 31/12/2013	Reanalysis	Own development
Bottom orbital speed (m/s)	01/01/1985 – 31/12/2013	Reanalysis	GOW (IH Cantabria)
Currents (m/s)	01/01/1985 – 31/12/2013	Reanalysis	GOST (IH Cantabria)

OSTIA, Operational Sea surface Temperature and sea-Ice concentration Analysis; NASA, National Aeronautics and Space Administration; CMIP5, World Climate Research Programme; GOW, Global Ocean Wave; GEBCO, General Bathymetric Chart of the Oceans; BODC, British Oceanographic Data Centre; ESA, European Space Agency; CFSR, NCEP Climate Forecast System Reanalysis; GOST, Global Ocean Surges Tides. All databases are at a spatial resolution of 0.1° and 0.5°, according to the defined mesh (Fig. 1).

calculations were based on hourly waves and currents data, obtained from GOW (Perez et al., 2017) and GOST (Cid et al., 2014) databases (Table 1), applying the formulation of Soulsby (Soulsby, 1997). The bed roughness was derived from the substrate type, according to Soulsby (1983). This formulation was selected because it has demonstrated good results in other studies (Roulund et al., 2016; Tomás et al., 2012). All variables were temporally homogenised through the compilation of raw to daily, when possible, or monthly data. For projections, parameters were calculated for each GCM, RCP and period, and averaged with the ensemble method (Arnell et al., 2014). For sea level projections, the IPCC values were considered (Slangen et al., 2014). Analyses were conducted using Climate Data Operators (CDO 1.7), NetCDF Operators (NCO 4.4.5), Matlab 8.1 and ArcGis 10.1.

3. Results and discussion

3.1. OCLE data

According to the aforementioned detected gaps, OCLE represents a step further in the capacity to characterize marine and coastal systems from an integrated temporal and spatial perspective. OCLE provides homogeneous and open access accurate information of 16 variables and 12 derived parameters for historical and projected periods, which completes the existing databases. Facing requirements for making predictions based on retrospective analysis of species distributions at different scales, this work has considered four fundamental aspects: (i) hydrodynamic characterization, (ii) spatial and temporal dimensions, (iii) biologically-meaningful parameters and (iv) reliable climate change projections.

(i) Hydrodynamic characterization

This is a key aspect because this type of variables are usually

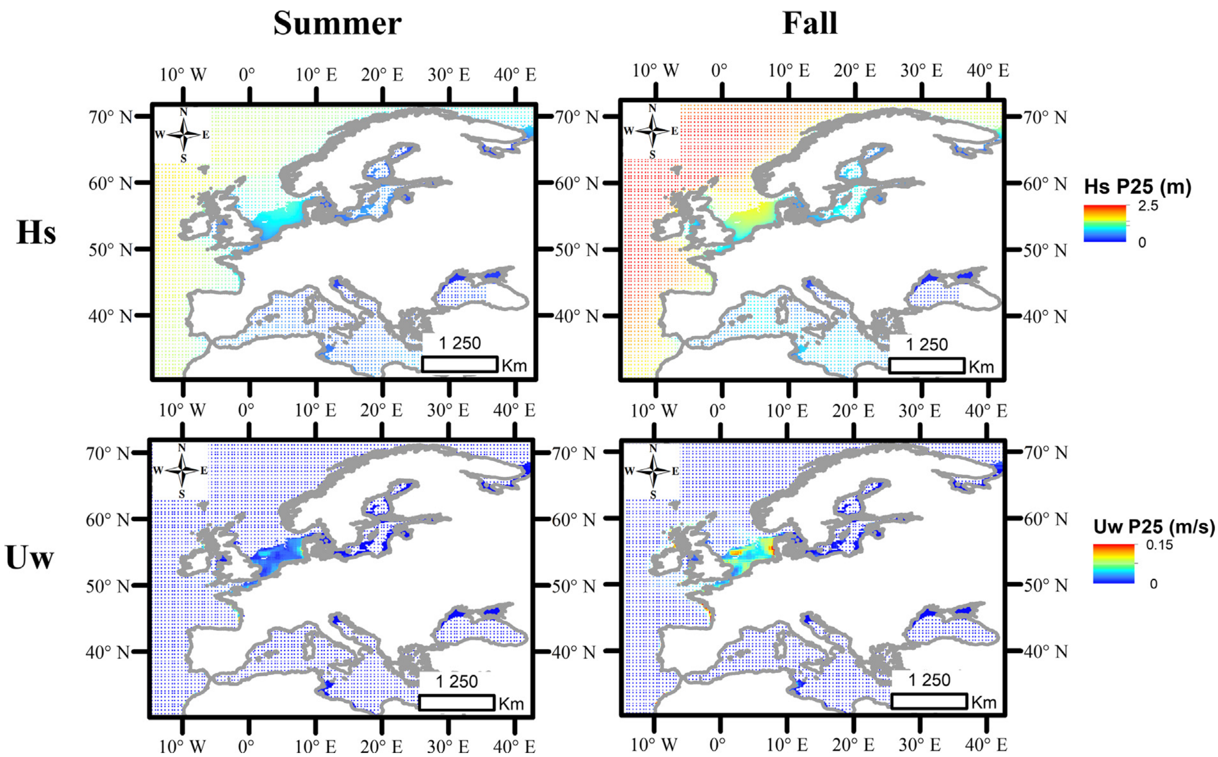

Fig. 3. Percentile 25 of significant wave height (Hs, upper panel) and currents (Uw, bottom panel), for summer (left) and fall (right) seasons.

omitted in other databases, despite their ecological importance for sessile species (Callaghan et al., 2015; de la Hoz et al., 2018; Pace et al., 2017; Ramos et al., 2016b). Furthermore, their temporal and spatial variability along the European seas constitutes a critical element to be considered for a holistic physical characterization. Consequently, it is essential to include variables that allow a complementary interpretation of the physical resistance of species, such as waves, currents and bottom orbital speed, both included in OCLE (Fig. 3).

One important contribution of OCLE is the development of a derived variable, the bottom shear stress, which allows detecting the areas where the energy of the system is higher and, consequently, the stress for benthic organisms (Pace et al., 2017). Although regional studies of bottom shear stress have been carried out by other authors (Alekseenko et al., 2017; Dalyander et al., 2013; Tomás et al., 2012), a broad scale characterization along Europe has not been developed so far. This gap has been solved in OCLE providing average and extreme parameters of bottom shear stress. The historical distribution of the winter 90th percentile reflects the spatial differences when considering potential bottom shear stress impacts on marine flora (Fig. 4), as previously demonstrated in the North Sea, the west coasts of Ireland or the Gulf of Gabès (Ben Brahim et al., 2015; Kregting et al., 2016; Schanz and Asmus, 2003).

(ii) Spatial and temporal dimensions

One of the first requirements in the design of an end-users oriented database is the integration of their needs. Most databases available provide a unique value for the whole period considered, which largely limits the type of hypothesis posed concerning prospective and retrospective trend analysis on species distribution (Thurstan et al., 2015). OCLE offers data with a higher resolution from daily or monthly to full period considered (Fig. 2). This allows detecting not only average environmental conditions, but also extreme conditions, which affect many species responses (Galván et al., 2016).

The interannual variability results crucial because species can respond to yearly episodes, most of them lost when using long-term averaged values. Similarly, intra-annual variability provides a huge potential for testing research questions regarding ecological responses of marine species versus historical and projected patterns in the abiotic environment linked to different natural or anthropogenic scenarios. For instance, seasonal differences in the potential influence of river (Spillman et al., 2007) or the industrial activity on nitrate discharges (Burson et al., 2016) may be estimated from Fig. 5 at the European scale.

Two spatial resolutions are available in OCLE in order to adapt the analysis scale and computing resources to the end-users needs. This allows addressing from general trend studies, at a spatial resolution of 0.5° (e.g. Fig. 3) to detailed studies, at 0.1° resolution (Fig. 6). In general terms, this dual approach will facilitate more precise studies at the coastal zone, where the influence on macrophytes-based communities occurs; whereas, a balance between a lower spatial resolution and a much more detailed abiotic information compared to previous works is available for oceanic areas. At the same time, OCLE opens the possibility for very specific studies by downscaling the variables at even higher resolutions (Galván et al., 2016; Tomás et al., 2016).

Finally, an important issue to ensure the potential applications of the database is the temporal and spatial homogeneity among variables. Some existing databases combine variables with diverse periods, due to the difficulty to collect temporal homogeneous data. However, a huge effort has been developed in this work to provide temporally homogeneous information for all variables (within the period 1985–2015), allowing the comparison among them (Table 1).

(iii) Biologically-meaningful parameters

Abiotic conditions that control the settlement, survival and reproduction of marine species are key factors that may determine, together with biological interactions, the species distribution (Araújo and Guisan, 2006). Currently, studies on specific thresholds for different physical and chemical variables affecting functional processes of macrophytes are mostly addressed in laboratory or *in situ* experiments. Their application to field conditions and under usually more complex environments may limit their transferability (Valiela, 2001). Variables and parameters established in OCLE have been selected to cover some ecological processes mainly related to the macroalgae and seagrasses distributions, for both average and extreme abiotic conditions. The later

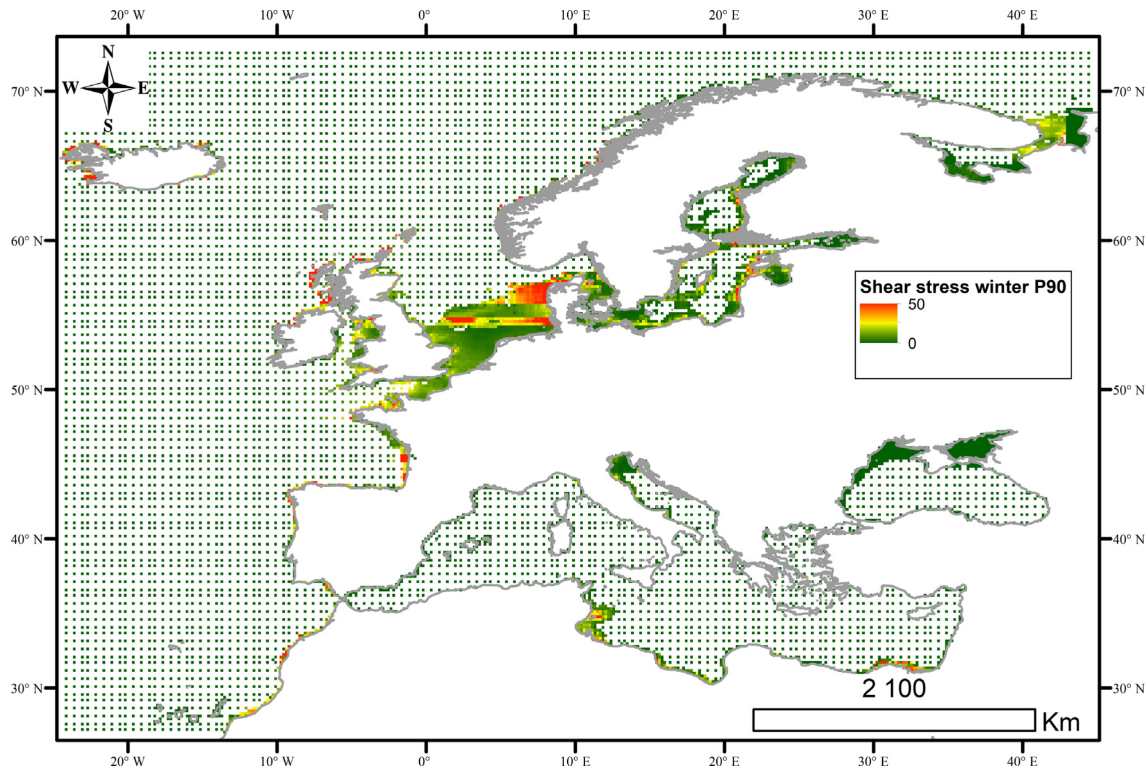

Fig. 4. Shear stress percentile 90 average values of all winters of the historical period (N/m^2).

ones are crucial for the survival of those species which are living in their limits of distribution (Araújo et al., 2016). In spite of the important advantages of OCLE, the involvement of the scientific community in the development of more specific parameters (Bosch et al., 2017) and the definition of other variables related to species distributions at different scales is necessary (Martínez et al., 2012a; Ramos et al., 2016a). For example, according to the threshold for bottom shear stress proposed by Vousdoukas et al. (2012), an analysis regarding the distribution of macrophytic communities through time (1985–2014) in response to the estimated increase in the stress in the intertidal zones is carried out along the coasts of Denmark (Fig. 6).

To arise the definition of these thresholds, the availability of a broad set of spatial and temporal information on biological-sounded parameters at the right scale is crucial. This information can be used in species distribution models (SDMs) for the statistical determination of limiting factors and the establishment of parameters response curves. This approach may be used as a proxy to understand the present and predict future distributions.

(iv) Reliable climate change projections

Concerning projections, OCLE does include, to our knowledge, the best information available (IPCC, 2014). Two future scenarios (RCP 4.5, RCP 8.5) were considered for the near (2040–2069) and long term (2070–2099), for eight of the variables (Table 1). Besides, the bias of the GCMs has been reduced thanks of the ensemble technique that has been applied in the quality control process (Camus et al., 2017; Meier et al., 2011) (Fig. 7).

3.2. OCLE website

OCLE results are available for free and stepwise download at http://ocle.ihcantabria.com, to allow users' choice of the most appropriate data for their research needs, regarding the period (historical or

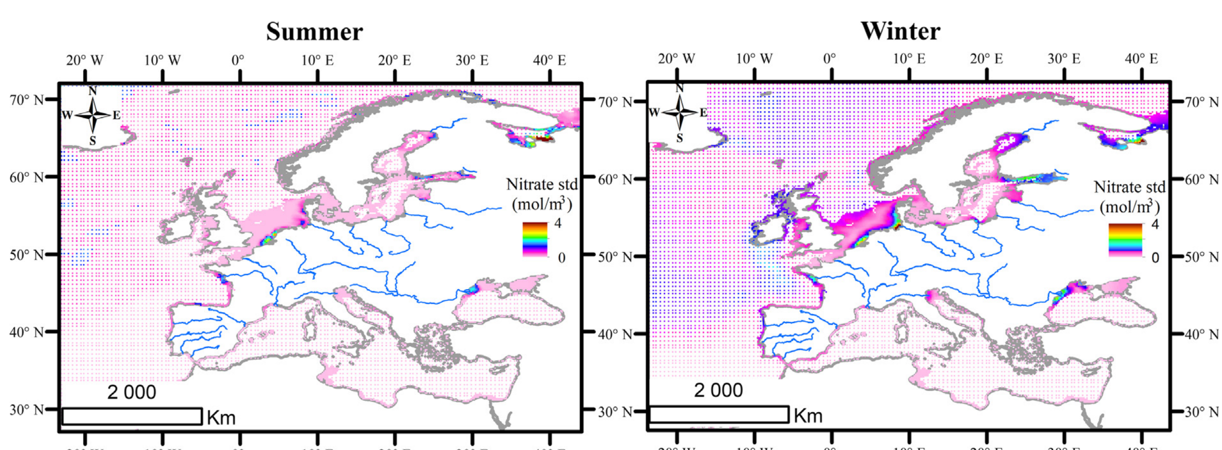

Fig. 5. Nitrate standard deviation of the year 2000 in summer (left) and winter (right). In blue, main European rivers. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

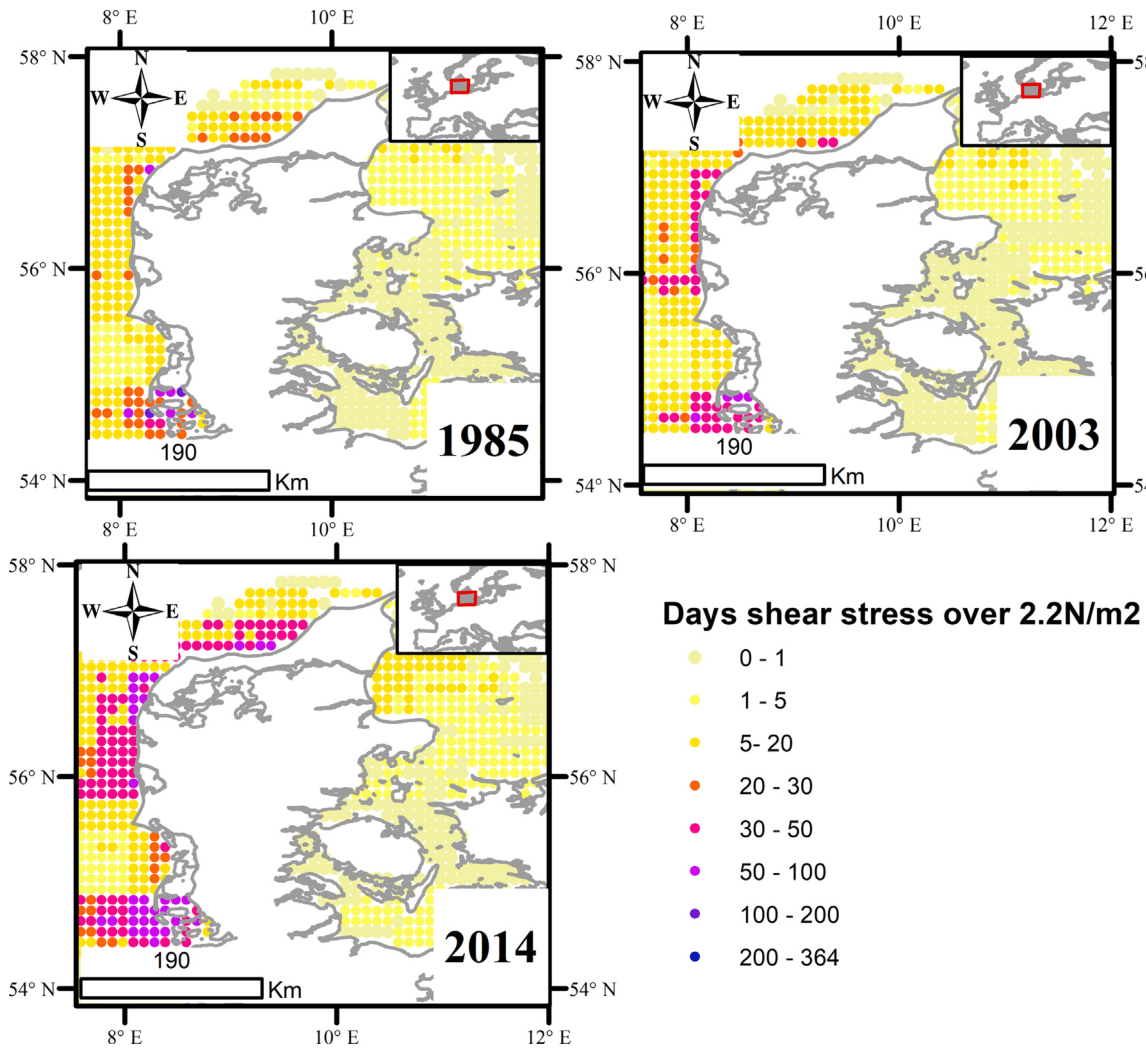

Fig. 6. Number of consecutive days in each year (1985 (top left), 2003 (top right) and 2014 (bottom left)) with bottom shear stress values over 2.2 N/m^2.

projected), the variables (16 options) and parameters of interest (12 choices). The full historical record (1985–2015) is split into five-yearly datasets.

Concerning projections, data for the near-term (2040–2069) and the long term (2070–2099) are available for each RCP considered. Researchers can select the datasets of interest and explore the data on a map or downloading the information in a .csv format to be used in SDMs or to be visualized in geographic information systems. To avoid computational overcharges, OCLE allows the spatial filtering, by zone selection over the map, coordinates screening, coastal areas (until 50 m depth) or predefined regions according to the European Commission (2008).

Additionally, it is possible to access to yearly data and customized parameters on request through the website. This opens up the possibility to a broad field of work generating more specific parameters.

4. Conclusions

The OCLE ecologically-driven database provides open access accurate abiotic information for research studies in European seas, complementing existing ones and addressing several gaps. Data are available at two spatial scales (0.1° and 0.5°) for long time series (1985–2015 and 2040–2099), which allows the definition of precise parameters to evaluate key factors affecting species distribution, such as the own developed variable bottom shear stress. The output format (.csv) can be used in diverse kinds of marine studies, with different purposes and scales, such as species distribution modelling or the physical and ecological classification of large areas (Calleja et al., 2017; de la Hoz et al., 2018; Ramos et al., 2012; Rueda et al., 2017).

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Data accessibility

The OCLE information is accessible online at http://ocle.ihcantabria.com for download (as csv files) and preview.

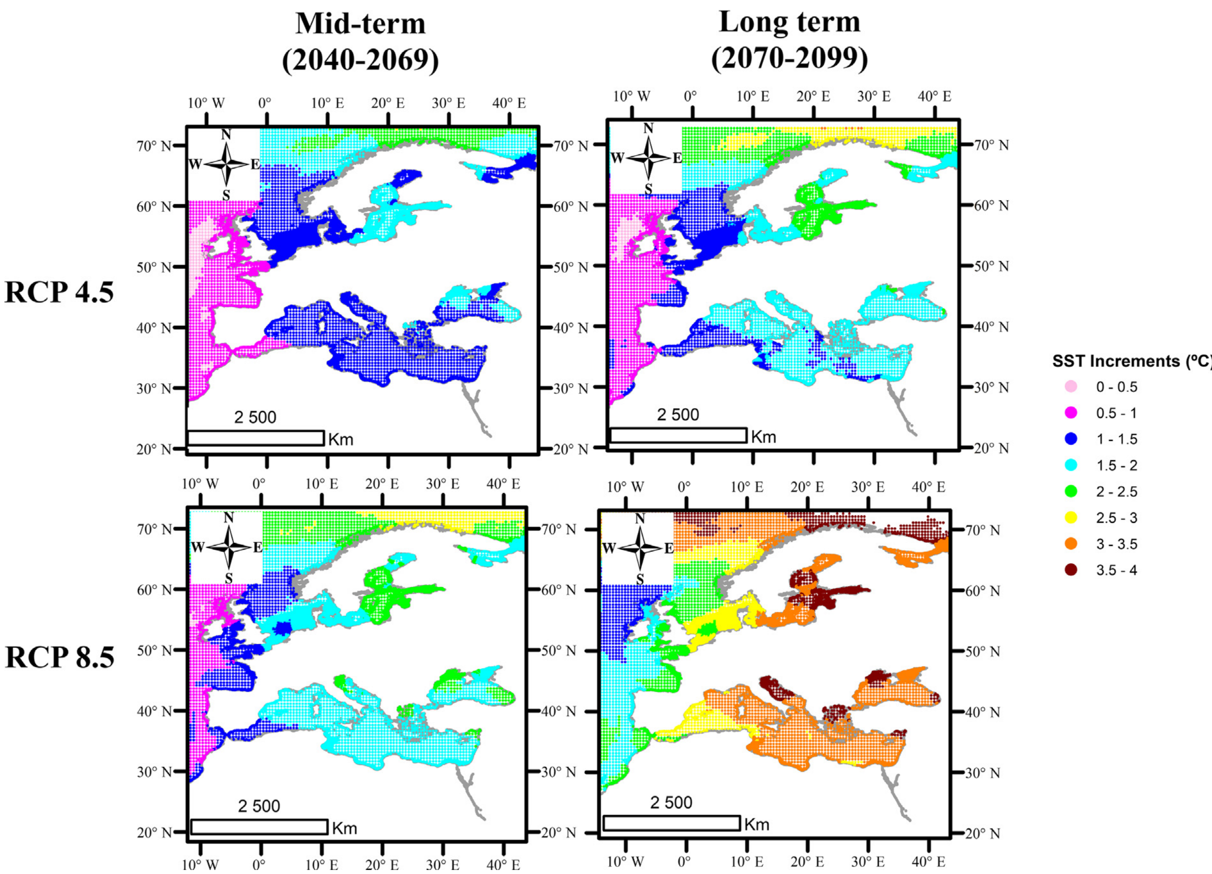

Fig. 7. SST increase with respect to the reference period for the RCP 4.5 (upper panel) and RCP 8.5 (lower panel) for the near-term (left) and long term (right).

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pocean.2018.09.021.

References

Alekseenko, E., Roux, B., Fougere, D., Chen, P.G., 2017. The effect of wind induced bottom shear stress and salinity on Zostera noltii replanting in a Mediterranean coastal lagoon. Estuar. Coast. Shelf Sci. 187, 293–305. https://doi.org/10.1016/j.ecss.2017.01.010.

Araújo, M.B., Guisan, A., 2006. Five (or so) challenges for species distribution modelling. J. Biogeogr. 33, 1677–1688. https://doi.org/10.1111/j.1365-2699.2006.01584.x.

Araújo, R.M., Assis, J., Aguillar, R., Airoldi, L., Bárbara, I., Bartsch, I., Bekkby, T., Christie, H., Davoult, D., Derrien-Courtel, S., Fernandez, C., Fredriksen, S., Gevaert, F., Gundersen, H., Le Gal, A., Lévêque, L., Mieszkowska, N., Norderhaug, K.M., Oliveira, P., Puente, A., Rico, J.M., Rinde, E., Schubert, H., Strain, E.M., Valero, M., Viard, F., Sousa-Pinto, I., 2016. Status, trends and drivers of kelp forests in Europe: an expert assessment. Biodivers. Conserv. 25, 1319–1348. https://doi.org/10.1007/s10531-016-1141-7.

Arnell, N.W., Brown, S., Gosling, S.N., Gottschalk, P., Hinkel, J., Huntingford, C., Lowe, J.A., Nicholls, R.J., Osborn, T.J., Osborne, T.M., Rose, G.A., Smith, P., Wheeler, T.R., Zelazowski, P., 2014. The impacts of climate change across the globe: A multi-sectoral assessment. Clim. Change 134, 457–474. https://doi.org/10.1007/s10584-014-1281-2.

Assis, J., Tyberghein, L., Verbruggen, H., Serrão, E., De Clerck, O., 2017. Bio-ORACLE v2.0: Extending marine data layers for bioclimatic modelling. Glob. Ecol. Biogeogr. 27, 277–284. https://doi.org/10.1111/geb.12693.

Ben Brahim, M., Mabrouk, L., Hamza, A., Mahfoudhi, M., Bouain, A., Aleya, L., 2015. Spatial scale variability in shoot density and epiphytic leaves of Posidonia oceanica on Kerkennah Island (Tunisia) in relation to current tide effects. Mar. Ecol. 36, 1311–1331. https://doi.org/10.1111/maec.12231.

Best, E.P., Buzzelli, C.P., Bartell, S.M., Wetzel, R.L., Boyd, W.A., Doyle, R.D., Campbell, K.R., 2001. Modeling submersed macrophyte growth in relation to underwater light climate: Modeling approaches and application potential. Hydrobiologia 444, 43–70. https://doi.org/10.1023/A:1017564632427.

Bosch, S., Tyberghein, L., Deneudt, K., Hernandez, F., De Clerck, O., 2017. In search of relevant predictors for marine species distribution modelling using the MarineSPEED benchmark dataset. Divers. Distrib. 24, 144–157. https://doi.org/10.1111/ddi.12668.

Burson, A., Stomp, M., Akil, L., Brussaard, C.P.D., Huisman, J., 2016. Unbalanced reduction of nutrient loads has created an offshore gradient from phosphorus to nitrogen limitation in the North Sea. Limnol. Oceanogr. 61, 869–888. https://doi.org/10.1002/lno.10257.

Callaghan, D.P., Leon, J.X., Saunders, M.I., 2015. Wave modelling as a proxy for seagrass ecological modelling: Comparing fetch and process-based predictions for a bay and reef lagoon. Estuar. Coast. Shelf Sci. 153, 108–120. https://doi.org/10.1016/j.ecss.2014.12.016.

Calleja, F., Galván, C., Silió-Calzada, A., Juanes, J.A., Ondiviela, B., 2017. Long-term analysis of Zostera noltei: A retrospective approach for understanding seagrasses' dynamics. Mar. Environ. Res. 130, 93–105. https://doi.org/10.1016/j.marenvres.2017.07.017.

Camus, P., Losada, Í.J., Izaguirre, C., Espejo, A., Menendez, M., Pérez, J., 2017. Statistical wave climate projections for coastal impact assessments. Earth's Futur. 5, 918–933. https://doi.org/10.1002/eft2.234.

Chai, T., Draxler, R.R., 2014. Root mean square error (RMSE) or mean absolute error (MAE)? -Arguments against avoiding RMSE in the literature. Geosci. Model Dev. 7, 1247–1250. https://doi.org/10.5194/gmd-7-1247-2014.

Cid, A., Castanedo, S., Abascal, A.J., Menéndez, M., Medina, R., 2014. A high resolution hindcast of the meteorological sea level component for Southern Europe: the GOS dataset. Clim. Dyn. 43, 1–18. https://doi.org/10.1007/s00382-013-2041-0.

Collins, M., Knutti, R., Arblaster, J., Dufresne, J.-L., Fichefet, T., Friedlingstein, P., Gao, X., Gutowski, W.J., Johns, T., Krinner, G., Shongwe, M., Tebaldi, C., Weaver, A.J., Wehner, M., 2013. Long-term climate change: projections, commitments and irreversibility. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA, pp. 1029–1136. doi:10.1017/CBO9781107415324.024.

Dalyander, P.S., Butman, B., Sherwood, C.R., Signell, R.P., Wilkin, J.L., 2013. Characterizing wave- and current- induced bottom shear stress: U.S. middle Atlantic continental shelf. Cont. Shelf Res. 52, 73–86. https://doi.org/10.1016/j.csr.2012.10.012.

de la Hoz, C.F., Ramos, E., Puente, A., Méndez, F.J., Menéndez, M., Juanes, J.A., Losada, I.J., 2018. Ecological typologies of large areas. An application in the Mediterranean Sea. J. Environ. Manage. 205, 59–72. https://doi.org/10.1016/j.jenvman.2017.09.058.

Donlon, C.J., Martin, M., Stark, J., Roberts-Jones, J., Fiedler, E., Wimmer, W., 2012. The operational sea surface temperature and sea ice analysis (OSTIA) system. Remote Sens. Environ. 116, 140–158. https://doi.org/10.1016/j.rse.2010.10.017.

Duarte, C.M., Losada, I.J., Hendriks, I.E., Mazarrasa, I., Marbà, N., 2013. The role of

coastal plant communities for climate change mitigation and adaptation. Nat. Clim. Chang. 3, 961–968. https://doi.org/10.1038/nclimate1970.
EEA, 2009. Rising sea temperatures, ice-free Arctic summers and a changing marine food chain. Copenhagen, Denmark.
European Commission, 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive), Official Journal of the European Communities.
Fautin, D.G., Buddemeier, R.W., 2002. Biogeoinformatics of hexacorallia (corals, sea anemones, and their allies): interfacing geospatial, taxonomic, and environmental data for a group of marine invertebrates.
Fralick, R.A., Baldwin, H.P., Neto, A.I., Hehre, E.J., 1990. Physiological responses of Pterocladia and Gelidium (Gelidiales, Rhodophyta) from the Azores, Portugal. Hydrobiologia 204, 479–482.
Galván, C., Puente, A., Castanedo, S., Juanes, J.A., 2016. Average vs. extreme salinity conditions: Do they equally affect the distribution of macroinvertebrates in estuarine environments? Limnol. Oceanogr. 61, 984–1000. https://doi.org/10.1002/lno.10267.
Garnesson, P., Mangin, A., Gohin, F., 2016. Quatliy information document. Ocean Colour - Global. Optics/Chlorophyll Observation Products.
Girvetz, E.H., Zganjar, C., Raber, G.T., Maurer, E.P., Kareiva, P., Lawler, J.J., 2009. Applied climate-change analysis: The climate Wizard tool. e8320. PLoS One 4 (12). https://doi.org/10.1371/journal.pone.0008320.
Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A., 2005. Very high resolution interpolated climate surfaces for global land areas. Int. J. Climatol. 25, 1965–1978. https://doi.org/10.1002/joc.1276.
Hughes, A.R.R., Bando, K.J., Rodriguez, L.F., Williams, S.L., 2004. Relative effects of grazers and nutrients on seagrasses: a meta-analysis approach. Mar. Ecol. Prog. Ser. 282, 87–99. https://doi.org/10.1016/j.cognition.2008.05.007.
Infantes, E., Orfila, A., Bouma, T.J., Simarro, G., Terrados, J., 2011. Posidonia oceanica and Cymodocea nodosa seedling tolerance to wave exposure. Limnol. Oceanogr. 56, 2223–2232. https://doi.org/10.4319/lo.2011.56.6.2223.
IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland.
Jones, T., Gardner, J.P.a., Bell, J.J., 2015. Modelling the effect of wave forces on subtidal macroalgae: A spatial evaluation of predicted disturbance for two habitat-forming species. Ecol. Modell. 313, 149–161. https://doi.org/10.1016/j.ecolmodel.2015.06.026.
Karger, D.N., Conrad, O., Böhner, J., Kawohl, T., Kreft, H., 2016. Climatologies at high resolution for the Earth land surface areas. World Data Center for Climate arXiv:1607.00217 [physics].
Kregting, L., Blight, A.J., Elsäßer, B., Savidge, G., 2016. The influence of water motion on the growth rate of the kelp Laminaria digitata. J. Exp. Mar. Bio. Ecol. 478, 86–95. https://doi.org/10.1016/j.jembe.2016.02.006.
Kriticos, D.J., Webber, B.L., Leriche, A., Ota, N., Macadam, I., Bathols, J., Scott, J.K., 2012. CliMond: Global high-resolution historical and future scenario climate surfaces for bioclimatic modelling. Methods Ecol. Evol. 3, 53–64. https://doi.org/10.1111/j.2041-210X.2011.00134.x.
Larkum, A., Orth, R.J., Duarte, C.M., 2006. Seagrasses: biology, ecology and conservation. Springer, Dordrecht (The Netherlands).
Lima, F.P., Wethey, D.S., 2012. Three decades of high-resolution coastal sea surface temperatures reveal more than warming. Nat. Commun. 3, 1–13. https://doi.org/10.1038/ncomms1713.
Lipkin, Y., Beer, S., Eshel, A., 1993. The ability of porphyra linearis (Rhodophyta) to tolerate prolonged periods of desiccation. Bot. Mar. 36, 517–524. https://doi.org/10.1515/botm.1993.36.6.517.
Martínez, B., Arenas, F., Rubal, M., Burgués, S., Esteban, R., García-Plazaola, I., Figueroa, F.L., Pereira, R., Saldaña, L., Sousa-Pinto, I., Trilla, A., Viejo, R.M., 2012a. Physical factors driving intertidal macroalgae distribution: Physiological stress of a dominant fucoid at its southern limit. Oecologia 170, 341–353. https://doi.org/10.1007/s00442-012-2324-x.
Martínez, B., Pato, L.S., Rico, J.M., 2012b. Nutrient uptake and growth responses of three intertidal macroalgae with perennial, opportunistic and summer-annual strategies. Aquat. Bot. 96, 14–22. https://doi.org/10.1016/j.aquabot.2011.09.004.
Mazarrasa, I., Marbà, N., Garcia-Orellana, J., Masqué, P., Arias-Ortiz, A., Duarte, C.M., 2017. Effect of environmental factors (wave exposure and depth) and anthropogenic pressure in the C sink capacity of Posidonia oceanica meadows. Limnol. Oceanogr. 62, 1436–1450. https://doi.org/10.1002/lno.10510.
Meier, H.E.M., Andersson, H.C., Eilola, K., Gustafsson, B.G., Kuznetsov, I., Mller-Karulis, B., Neumann, T., Savchuk, O.P., 2011. Hypoxia in future climates: A model ensemble study for the Baltic Sea. Geophys. Res. Lett. 38, 1–6. https://doi.org/10.1029/2011GL049929.
Nejrup, L.B., Pedersen, M.F., 2008. Effects of salinity and water temperature on the ecological performance of Zostera marina. Aquat. Bot. 88, 239–246. https://doi.org/10.1016/j.aquabot.2007.10.006.
Ondiviela, B., Losada, I.J., Lara, J.L., Maza, M., Galván, C., Bouma, T.J., van Belzen, J., 2014. The role of seagrasses in coastal protection in a changing climate. Coast. Eng. 87, 158–168. https://doi.org/10.1016/j.coastaleng.2013.11.005.
Pace, M., Borg, J.A., Galdies, C., Malhotra, A., 2017. Influence of wave climate on architecture and landscape characteristics of Posidonia oceanica meadows. Mar. Ecol. 38, 1–14. https://doi.org/10.1111/maec.12387.
Pearson, G.a., Lago-Leston, A., Mota, C., 2009. Frayed at the edges: Selective pressure and adaptive response to abiotic stressors are mismatched in low diversity edge populations. J. Ecol. 97, 450–462. https://doi.org/10.1111/j.1365-2745.2009.01481.x.
Perez, J., Menendez, M., Losada, I.J., 2017. GOW2: A global wave hindcast for coastal applications. Coast. Eng. 124, 1–11. https://doi.org/10.1016/j.coastaleng.2017.03.005.
Perez, J., Menendez, M., Mendez, F.J., Losada, I.J., 2014. Evaluating the performance of CMIP3 and CMIP5 global climate models over the north-east Atlantic region. Clim. Dyn. 43, 2663–2680. https://doi.org/10.1007/s00382-014-2078-8.
Perruche, C., Paul, J., Drévillon, M., 2015. Quality information document for global biogeochemical non assimilative hindcast product.
Ramos, E., Díaz de Terán, J.R., Puente, A., Juanes, J.A., 2016a. The role of geomorphology in the distribution of intertidal rocky macroalgae in the NE Atlantic region. Estuar. Coast. Shelf Sci. 179, 90–98. https://doi.org/10.1016/j.ecss.2015.10.007.
Ramos, E., Juanes, J.A., Galván, C., Neto, J.M., Melo, R., Pedersen, A., Scanlan, C., Wilkes, R., van den Bergh, E., Blomqvist, M., Karup, H.P., Heiber, W., Reitsma, J.M., Ximenes, M.C., Silió, A., Méndez, F., González, B., 2012. Coastal waters classification based on physical attributes along the NE Atlantic region. An approach for rocky macroalgae potential distribution. Estuar. Coast. Shelf Sci. 112, 105–114. https://doi.org/10.1016/j.ecss.2011.11.041.
Ramos, E., Puente, A., Juanes, J.A., 2016b. An ecological classification of rocky shores at a regional scale: a predictive tool for management of conservation values. Mar. Ecol. 37, 311–328. https://doi.org/10.1111/maec.12280.
Ramos, E., Puente, A., Juanes, J.A., Neto, J.M., Pedersen, A., Bartsch, I., Scanlan, C., Wilkes, R., Van den Bergh, E., Ar Gall, E., Melo, R., 2014. Biological validation of physical coastal waters classification along the NE Atlantic region based on rocky macroalgae distribution. Estuar. Coast. Shelf Sci. 147, 103–112. https://doi.org/10.1016/j.ecss.2014.05.036.
Ready, J., Kaschner, K., South, A.B., Eastwood, P.D., Rees, T., Rius, J., Agbayani, E., Kullander, S., Froese, R., 2010. Predicting the distributions of marine organisms at the global scale. Ecol. Modell. 221, 467–478. https://doi.org/10.1016/j.ecolmodel.2009.10.025.
Reguero, B.G., Menéndez, M., Méndez, F.J., Mínguez, R., Losada, I.J., 2012. A Global Ocean Wave (GOW) calibrated reanalysis from 1948 onwards. Coast. Eng. 65, 38–55. https://doi.org/10.1016/j.coastaleng.2012.03.003.
Rhein, M., Rintoul, S.R., Aoki, S., Campos, E., Chambers, D., Freely, R.A., 2013. Climate change 2013. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J. (Eds.), The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, New York, pp. 255–316.
Robinson, N.M., Nelson, W.A., Costello, M.J., Sutherland, J.E., Lundquist, C.J., 2017. A systematic review of marine-based species distribution models (SDMs) with recommendations for best practice. Front. Mar. Sci. 4, 1–11. https://doi.org/10.3389/fmars.2017.00421.
Roulund, A., Sutherland, J., Todd, D., Sterner, J., 2016. Parametric equations for Shields parameter and wave orbital velocity in combined current and irregular waves. In: Harris, J., Whitehouse, R., Moxon, S. (Eds.), 8 Th International Conference of Scour and Erosion. Taylor & Francis Group, Oxford, UK, pp. 313–318.
Rueda, A., Vitousek, S., Camus, P., Tomás, A., Espejo, A., Losada, I.J., Barnard, P.L., Erikson, L.H., Ruggiero, P., Reguero, B.G., Mendez, F.J., 2017. A global classification of coastal flood hazard climates associated with large-scale oceanographic forcing. Sci. Rep. 7, 5038. https://doi.org/10.1038/s41598-017-05090-w.
Saha, S., Moorthi, S., Pan, H.L., Wu, X., Wang, J., Nadiga, S., Tripp, P., Kistler, R., Woollen, J., Behringer, D., Liu, H., Stokes, D., Grumbine, R., Gayno, G., Wang, J., Hou, Y.T., Chuang, H.Y., Juang, H.M.H., Sela, J., Iredell, M., Treadon, R., Kleist, D., Van Delst, P., Keyser, D., Derber, J., Ek, M., Meng, J., Wei, H., Yang, R., Lord, S., Van Den Dool, H., Kumar, A., Wang, W., Long, C., Chelliah, M., Xue, Y., Huang, B., Schemm, J.K., Ebisuzaki, W., Lin, R., Xie, P., Chen, M., Zhou, S., Higgins, W., Zou, C.Z., Liu, Q., Chen, Y., Han, Y., Cucurull, L., Reynolds, R.W., Rutledge, G., Goldberg, M., 2010. The NCEP climate forecast system reanalysis. Bull. Am. Meteorol. Soc. 91, 1015–1057. https://doi.org/10.1175/2010BAMS3001.1.
Saha, S., Moorthi, S., Wu, X., Wang, J., Nadiga, S., Tripp, P., Behringer, D., Hou, Y.T., Chuang, H.Y., Iredell, M., Ek, M., Meng, J., Yang, R., Mendez, M.P., Van Den Dool, H., Zhang, Q., Wang, W., Chen, M., Becker, E., 2014. The NCEP climate forecast system version 2. J. Clim. 27, 2185–2208. https://doi.org/10.1175/JCLI-D-12-00823.1.
Sbrocco, E.J., Barber, P.H., 2013. MARSPEC: ocean climate layers for marine spatial ecology. Ecology 94, 979. https://doi.org/10.1890/12-1358.1.
Schanz, A., Asmus, H., 2003. Impact of hydrodynamics on development and morphology of intertidal seagrasses in the Wadden Sea. Mar. Ecol. Prog. Ser. 261, 123–134. https://doi.org/10.3354/meps261123.
Schuckmann, K. Von, Traon, P. Le, Alvarez-fanjul, E., Axell, L., Balmaseda, M., Breivik, L.-A., Brewin, R.J.W., Bricaud, C., Drevillon, M., Drillet, Y., Dubois, C., Embury, O., Etienne, H., Sotillo, M.G., Garric, G., Gasparin, F., Gutknecht, E., Guinehut, S., Hernandez, F., Juza, M., Karlson, B., Korres, G., Legeais, J.-F., Levier, B., Lien, V.S., Morrow, R., Notarstefano, G., Parent, L., Pascual, Á., Pérez-Gómez, B., Perruche, C., Pinardi, N., Pisano, A., Poulain, P.-M., Pujol, I.M., Raj, R.P., Raudsepp, U., Roquet, H., Samuelsen, A., Sathyendranath, S., She, J., Simoncelli, S., Solidoro, C., Tinker, J., Tintoré, J., Viktorsson, L., Ablain, M., Almroth-Rosell, E., Bonaduce, A., Clementi, E., Cossarini, G., Dagneaux, Q., Desportes, C., Dye, S., Fratianni, C., Good, S., Greiner, E., Gourrion, J., Hamon, M., Holt, J., Hyder, P., Kennedy, J., Manzano-Muñoz, F., Melet, A., Meyssignac, B., Mulet, S., Nardelli, B.B., O'Dea, E., Olason, E., Paulmier, A., Pérez-González, I., Reid, R., Racault, M.-F., Raitsos, D.E., Ramos, A., Sykes, P., Szekely, T., Verbrugge, N., 2016. The copernicus marine environment monitoring service ocean state report. J. Oper. Oceanogr. 9, 235–320. https://doi.org/10.1080/1755876X.2016.1273446.
Seabra, R., Wethey, D.S., Lima, F.P., Campo, R., 2015. Understanding complex biogeographic responses to climate change. Sci. Rep. 5, 1–6. https://doi.org/10.1038/srep12930.
Short, F.T., Neckles, H.A., 1999. The effects of global climate change on seagrasses. Aquat. Bot. 63, 169–196. https://doi.org/10.1016/S0304-3770(98)00117-X.

Slangen, A.B.A., Carson, M., Katsman, C.A., van de Wal, R.S.W., Vermeersen, L.L.A., Stammer, D., 2014. Projecting twenty-first century regional sea-level changes. Clim. Change 124, 317–332. https://doi.org/10.1007/s10584-014-1080-9.
Soulsby, R.L., 1983. The bottom boundary layer of shelf seas. In: Physical Oceanography of Coastal and Shelf Seas. Elsevier, Amsterdam, pp. 189–266. https://doi.org/10.1016/S0422-9894(08)70503-8.
Soulsby, R.L., 1997. Dynamics of marine sands: a manual for practical applications, Dynamics of marine sands: a manual for practical applications. London. https://doi.org/10.1680/doms.25844.
Spillman, C.M., Imberger, J., Hamilton, D.P., Hipsey, M.R., Romero, J.R., 2007. Modelling the effects of Po River discharge, internal nutrient cycling and hydrodynamics on biogeochemistry of the Northern Adriatic Sea. J. Mar. Syst. 68, 167–200. https://doi.org/10.1016/j.jmarsys.2006.11.006.
Stark, J.D., Donlon, C.J., Martin, M.J., McCulloch, M.E., 2007. OSTIA : An operational, high resolution, real time, global sea surface temperature analysis system. In: OCEANS 2007. Marine Challenges: Coastline to Deep Sea. Aberdeen, Scotland, pp. 1–4. doi: 10.1109/OCEANSE.2007.4302251.
Taylor, K.E., Stouffer, R.J., Meehl, G.A., Taylor, K.E., Stouffer, R.J., Meehl, G.A., 2012. An overview of CMIP5 and the experiment design. Bull. Am. Meteorol. Soc. 93, 485–498. https://doi.org/10.1175/BAMS-D-11-00094.1.
Thurstan, R.H., McClenachan, L., Crowder, L.B., Drew, J.A., Kittinger, J.N., Levin, P.S., Roberts, C.M., Pandolfi, J.M., 2015. Filling historical data gaps to foster solutions in marine conservation. Ocean Coast. Manag. 115, 31–40. https://doi.org/10.1016/j.ocecoaman.2015.04.019.
Tomás, A., Méndez, F.J., Losada, Í.J., 2012. Bed shear stress during Sant Estevés storm (26th December 2008) along the Cataloniás coast (NW Mediterranean).
Tomás, A., Méndez, F.J., Medina, R., Jaime, F.F., Higuera, P., Lara, J.L., Ortiz, M.D., Álvarez de Eulate, M.F., 2016. A methodology to estimate wave-induced coastal flooding hazard maps in Spain. J. Flood Risk Manag. 9, 289–305. https://doi.org/10.1111/jfr3.12198 Key.
Torresan, S., Critto, A., Rizzi, J., Zabeo, A., Furlan, E., Marcomini, A., 2016. DESYCO: A decision support system for the regional risk assessment of climate change impacts in coastal zones. Ocean Coast. Manag. 120, 49–63. https://doi.org/10.1016/j.ocecoaman.2015.11.003.
Touchette, B.W., 2007. Seagrass-salinity interactions: Physiological mechanisms used by submersed marine angiosperms for a life at sea. J. Exp. Mar. Bio. Ecol. 350, 194–215. https://doi.org/10.1016/j.jembe.2007.05.037.
Tyberghein, L., Verbruggen, H., Pauly, K., Troupin, C., Mineur, F., De Clerck, O., 2012. Bio-ORACLE: A global environmental dataset for marine species distribution modelling. Glob. Ecol. Biogeogr. 21, 272–281. https://doi.org/10.1111/j.1466-8238.2011.00656.x.
Valiela, I., 2001. Doing Science: Design, Analysis, and Communication of Scientific Research. Oxford University Press, New York.
Valle, M., Chust, G., del Campo, A., Wisz, M.S., Olsen, S.M., Garmendia, J.M., Borja, Á., 2014. Projecting future distribution of the seagrass Zostera noltii under global warming and sea level rise. Biol. Conserv. 170, 74–85. https://doi.org/10.1016/j.biocon.2013.12.017.
Vega, G.C., Pertierra, L.R., Olalla-Táraga, M.Á., 2017. MERRAclim, a high-resolution global dataset of remotely sensed bioclimatic variables for ecological modelling. 170078. Sci. Data 4. https://doi.org/10.1038/sdata.2017.78.
Vousdoukas, M.I., Velegrakis, A.F., Paul, M., Dimitriadis, C., Makrykosta, E., Koutsoubas, D., 2012. Field observations and modeling of wave attenuation over colonized beachrocks. Cont. Shelf Res. 48, 100–109. https://doi.org/10.1016/j.csr.2012.08.015.
Weatherall, P., Marks, K.M., Jakobsson, M., Schmitt, T., Tani, S., Arndt, J.E., Rovere, M., Chayes, D., Ferrini, V., Wigley, R., 2015. A new digital bathymetric model of the world's oceans. Earth Sp. Sci. 2, 331–345. https://doi.org/10.1002/2015EA000107.Received.
Young, M., Ierodiaconou, D., Womersley, T., 2015. Forests of the sea: Predictive habitat modelling to assess the abundance of canopy forming kelp forests on temperate reefs. Remote Sens. Environ. 170, 178–187. https://doi.org/10.1016/j.rse.2015.09.020.